Influence of Variation in Sediment Conditions on the Acoustic Response of Targets near the Sea Floor

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LONG-TERM GOALS

Detection and classification of objects on or imbedded in the ocean sediment is a problem receiving increasing attention. The measured scattering in these situations will include interactions of the incident sound with the sediment interface itself, as well as the possibility for multiple interactions between the target and sediment. This research focuses on the problem of variation in sediment properties and their effect on target responses. The long-term goals are to understand, and quantitatively predict, the effects of the environment on scattering from mines and mine-like targets. First, attempts will be made to understand the role that the interface plays on the measured scattering from proud and buried targets. Secondly, some attention will be spent on aspects pertaining to the classification of targets, specifically on understanding how the variation in scattering due to interface condition affects the classification schemes used in mine counter-measures (MCM).

OBJECTIVES

Ultimately, any sort of identification/classification schemes employed by the U.S. Navy will have to address two issues in order to be effective: 1) quantitative understanding of the acoustic response of objects in contact with or embedded in the ocean sediment and 2) how variation in the sediment conditions affect the acoustic response of such targets. The main objective this year aimed at identifying how various aspects of the target physics contribute to the acoustic scattering and how this is affected by the presence of the sediment. However, looking ahead to the long-term goal of understanding the role that variation in sediment plays in the acoustic scattering, the second objective was to ensure that experiments were designed and conducted that would look at the role played by the sediment properties, albeit leaving the interpretation of these results to the focus of FY11.

APPROACH

Experimental measurements and modeling techniques are combined to accomplish the objectives of this research.

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Experiments:
The experiments consisted of: (A) studying the acoustic scattering from an aluminum water-filled pipe in the free field, (B) studying the acoustic response of the pipe and other mine-like targets in contact with a sand sediment, and (C) studying the acoustic response of the pipe and other mine-like targets in contact with other interfaces of known reflection coefficients. The free field measurements of (A) serve as a base to establishing the acoustic response of the target and help to identify how specific aspects of the target physics govern the observed acoustic scattering. Subsequently placing the same target in contact with a sand sediment in (B) serves to identify the role that the sediment plays in the observed acoustic scattering. Finally, the purpose of the experiments described in (C) is to determine how variation in sediment properties affects the acoustic response of the target. Changes to sediment properties, or essentially changes to the phase of the reflection coefficients, affect the reflected acoustic energy and how it interacts with the target. Since the physics governing the coupling of acoustic energy to the elastic response of the target has not changed, it is the variation in the conditions of the environment that causes any observed differences.

All experiments were conducted on-base at the Naval Surface Warfare Center, Panama City Division (NSWC PCD). Two test facilities were utilized, the details of which are described in what follows. A detailed list of each of the relevant experiments completed during FY10 is listed in the "Work Completed" section.

The majority of experiments were conducted in the NSWC PCD test pond during FY10 in collaboration with NSWC PCD personnel. The pond is 110 m long and 80 m wide, and is filled with approximately 9 million gallons of water. A 1.5 m layer of sand fills the bottom of the pond. A detailed aerial view of the test pond can be seen in [1]. Data acquisition is achieved through the use of a rail and mobile tower system. The rail system is deployed in sections and assembled underwater by divers, its final length measuring 21 m. The tower houses an array on which sources and receivers are mounted. The tower transverses over 19.1 m of the rail, the source pinging approximately once every 2.5 cm. The array can be tilted in order to point the source/receivers in the appropriate direction to accommodate free field or proud experiments. For a schematic of the rail, tower and array refer to [1]. For the free field experiment pertaining to (A), the target of interest is an aluminum pipe, 0.6096 m in length, with an inner diameter measuring 0.3048 m, and pipe wall thickness of 0.0095 m. Two stationary tripods were deployed 10 m away from the rail system with the approximate separation of 6 m. A line was strung between these two tripods and through the pipe so that the pipe was suspended approximately 2 m off the bottom and broadside to the rail. Further experimentation on the acoustic scattering from the pipe in the free field was conducted in the Acoustic Test Facility (ATF) at NSWC PCD. A source and receiver array were suspended mid-water column, the separation between the two being approximately 1.2 m. The pipe was suspended mid-water column, 9 m from the source and receiver. For this experiment, the source and receiver positions were fixed, and the pipe was rotated from 0 to 90 deg in 1 deg increments.

The proud experiments (B) were conducted in the test pond and some discussion is merited on the target field preparation. The sand was flattened and smoothed in five different target patches. Each patch was 1 m^2 in size and located a horizontal distance of 10 m away from the rail/tower system. The center-to-center distance between adjacent patches was about 3 m. Targets were deployed simultaneously in the center of the target patches. The targets studied included the aluminum pipe, a solid aluminum cylinder, and a number of unexploded ordnance (UXO) shaped objects with cylindrical symmetry. The typical target size was 1 to 2 ft, resulting in a 3 m separation between each adjacent target. Finally, the array was tilted down toward the sediment, resulting in grazing incidence of ~ 20

degrees [2,3]. The acoustic scattering was measured as a function of aziumuthal angle. Supporting environmental measurements were made of the bulk and interface properties.

Finally, two experiments were designed to investigate the scattering from targets near interfaces with known reflection coefficients as described in (C). For the first experiment, a foam raft was designed and fabricated. The foam behaves like a pressure release surface, the reflection coefficient being R = -1. The pipe was attached to the belly of the foam raft in a broadside orientation to the rail, and the whole contraption was deployed at the surface of the pond at a horizontal range of 10 m from the rail system. For the second experiment, flat, plexiglass panels were placed down on the sediment interface. The aluminum pipe and solid cylinder were positioned on these panels and the acoustic scattering was measured as a function of azimuthal angle.

<u>Modeling</u>:
To aid in the interpretation of the experimental results, numerical simulations will be conducted of the scattered acoustic field for the various targets in each of the different environmental conditions (free field, proud on sand, etc.). Focusing on the specific objectives of FY10, a finite element (FE) model is developed for the pipe in the free field. These results will be compared with the experimental data and with physical acoustic based models currently under development [4]. Modeling efforts during FY11 will transition to looking at the pipe in contact with sand, foam and plexiglass, in addition to modeling the other UXO shaped targets which have more complicated geometry.

<u>Key Individuals:</u>
Dr. Aubrey L. España is the principle investigator in this project. Dr. España was responsible for the planning and execution of the experimental aspects of this research. Drs. Kevin L. Williams and Steven G. Kargl provided insight and guidance pertaining to the pond experiments, while Dr. Joseph Lopes advised the experiments conducted in the NSWC PCD's ATF tank. The free field FE model was developed by Dr. España and Dr. Mario Zampolli. Their collaboration will continue into FY11 with the development of FE models for the pipe and other UXO shaped targets in proud configurations on the sediment.

WORK COMPLETED

Table 1 lists all of the experiments completed during FY10. The experiments are labeled based on the category it falls into as described in the "Approach" section (A, B, or C).

<u>Modeling</u>:
A finite element (FE) model has been developed for the aluminum pipe in the free field, the results of which are presented in the section. The model takes advantage of the axial symmetry of the problem, and builds up the full 3-D result from multiple 2-D calculations. The specific source-receiver-target geometry is easily changed so as to accommodate either the pond experimental geometry or ATF geometry. The details of this model are discussed in [**Error! Bookmark not defined.**]. This free field model serves as the stepping-stones for a proud model that is currently under development.

Table 1. Experiments completed during spring of FY10 at NSWC PCD.

Exp. Classification	Source	Target(s)	Angle Range	Description
A – pond	LFM pulse 6 ms, 1-30kHz	Alum. Pipe	Broadside	Free field
A – ATF	LFM pulse 1.5 ms, 8-40kHz	Alum. Pipe	0 – 90 deg	Free field
B – pond	LFM pulse 6 ms, 1-30kHz	Alum. Pipe Alum. Cyl Alum. UXO Steel UXO	0 – 90 deg 0 – 90 deg 0 – 180 deg 0 – 180 deg	Proud on sand sediment
C – pond	LFM pulse 6 ms, 1-30kHz	Alum. Pipe	Broadside	Pipe in contact with foam raft
C – pond	LFM pulse 6 ms, 1-30kHz	Alum. Pipe Alum. Cyl	0 – 90 deg	Proud on plexiglass plates

RESULTS

(1) Impact of sediment presence to the measured acoustic scattering from an aluminum pipe:
Figures 1 (a) and **(b)** illustrate the effect that the presence of the sediment has on the acoustic scattering from an aluminum pipe. The absolute target strength is plotted as a function of azimuthal tilt angle for: **(a)** the free field experiment conducted in the NSWC PCD's ATF, and **(b)** the pond experiment for the pipe in a proud configuration on the sand sediment. The presence of the sediment brings about a number of bright phenomena that were otherwise not visible in the acoustic response of the target in the free field, specifically in the region from about 10-20 deg. and 45-75 deg. These results are not surprising since it is already well known that the presence of the sediment results in the existence of multipaths between the target and interface and ultimately alters how the sound couples and interacts with the target (see [**Error! Bookmark not defined.**] for example). The significance of these results however are to serve as a base for which to compare the acoustic response of the pipe in contact with different interfaces (foam and plexiglass). Efforts during FY11 will focus on interpreting the experimental results from these different interfaces and comparing to those of **Fig. 1**. This will aid in developing an acoustic template based classification scheme that accounts for variation in sediment properties.

(2) Influence of the target physics on the measured acoustic scattering from an aluminum pipe:
The free field and proud data taken in the test pond are processed using a frequency-domain synthetic aperture sonar (SAS) technique. **Figure 2 (a)** shows the SAS image for the aluminum pipe suspended mid-water column in the pond, broadside to the rail system. Although a physical acoustics based ray model has not been developed yet, it is safe to assume that the first bright feature is associated with the specular return from the pipe. The late time features are associated with the elastic response of the pipe and clearly indicate that the pipe has a number of resonances that ring for a significant time. **Figure 2 (b)** is the SAS image of the pipe proud on the sand sediment. Since multiple targets are deployed simultaneously during these proud experiments, a "reversible SAS algorithm" is employed in order to isolate a single target response. This method is described in detail in [5]. As can be seen in **Fig. 2 (b)**, the specular piece is now made up of three contributions corresponding to the three ray

paths that sound can take as it travels between the source, interface and target. In addition, the pipe again has significant elastic contributions based on the long tail observed following the specular returns. By applying spatial filtering boundaries to the SAS data, it's possible to see how the target response of the pipe is built up in terms of the different specular and elastic effects comprising the scattered field. The spatial boundaries applied to the data are indicated by the black boxes drawn on the SAS images of **Fig. 2**. The small black box on the left includes only the specular piece and is represented by the blue (long dashed) curve in **Fig. 3** (**(a)** free field, **(b)** proud). The box on the right comprises only the elastic response of the target and is represented by the black (short dashed) curve. Finally the two boxes taken together make up the total response of the pipe and is the red (solid) curve. For both free field and proud results, the specular response appears to drive the overall level of the total target response, while the elastic features account for the fine structure that is observed. However, below ~ 7 kHz the target response appears to be driven by the elastic effects. Overall, the way in which the specular and elasic responses of the target make up the total target response was not affected by the presence of the sediment.

(3) <u>Numerical simulations of the acoustic scattering from an aluminum pipe in the free field:</u>
An FE model was developed for the pipe suspended in the free field, and could be programmed to accommodate either the pond experimental geometry or the ATF geometry. **Figure 4** shows the results for the FE model corresponding to the case of broadside orientation with respect to the rail in the pond experiment. The absolute target strength is plotted as a function of frequency. Also shown in this plot are the free field pond experimental results from **Fig. 3 (a)** (red curve). There is good agreement between the model and the data. Fourier transforms of these finite element results allow for the separation of the specular and elastic structures in time. Thus, results identical to **Fig. 3** can be constructed following a transform back into frequency space. The results of this calculation are given in **Fig. 5**. These results serve as confirmation that the specular drives the overall target level and the elastic effects make up the fine structure above about 7 kHz.

IMPACT/APPLICATIONS

This research helps explain the acoustic response of targets in contact with a sediment interface. The acoustic scattering in these sitiuations is highly dependant on both the target physics and the environment properties. While these two driving forces cannot be decoupled from eachother, this research outlines experimental and modeling techniques that serve to identify the role played by each in building up the final acoustic response. In the coming year, this work will provide a better understanding of the relationship between the sediment properties and the resulting scattering from targets. This is key when trying to accurately interpret, and eventually classify, measurements from mines and mine-like targets. Future development of acoustic templates for the scattering from targets in contact with different types of interfaces will aid in the development of a feature-based classification scheme.

RELATED PROJECTS

The present research is closely coordinated with theoretical and experimental efforts ongoing at APL-UW (E. Thorsos and S. Kargl) and at NSWC PCD (J. Lopes, D. Burnett, and R. Lim) under support from the Office of Naval Research (ONR) Codes 321OA, 321OE, 321MS, and the SERDP to resolve bottom target scattering issues with D. Burnett developing a numerical approach based on FE to model acoustic scattering and radiation by complex three-dimensional objects near boundaries.

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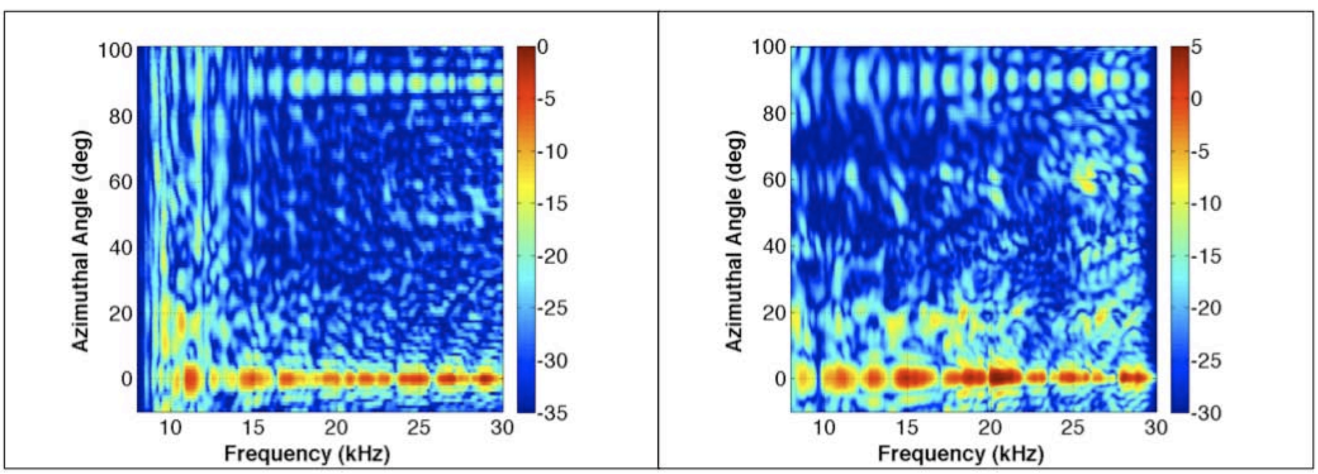
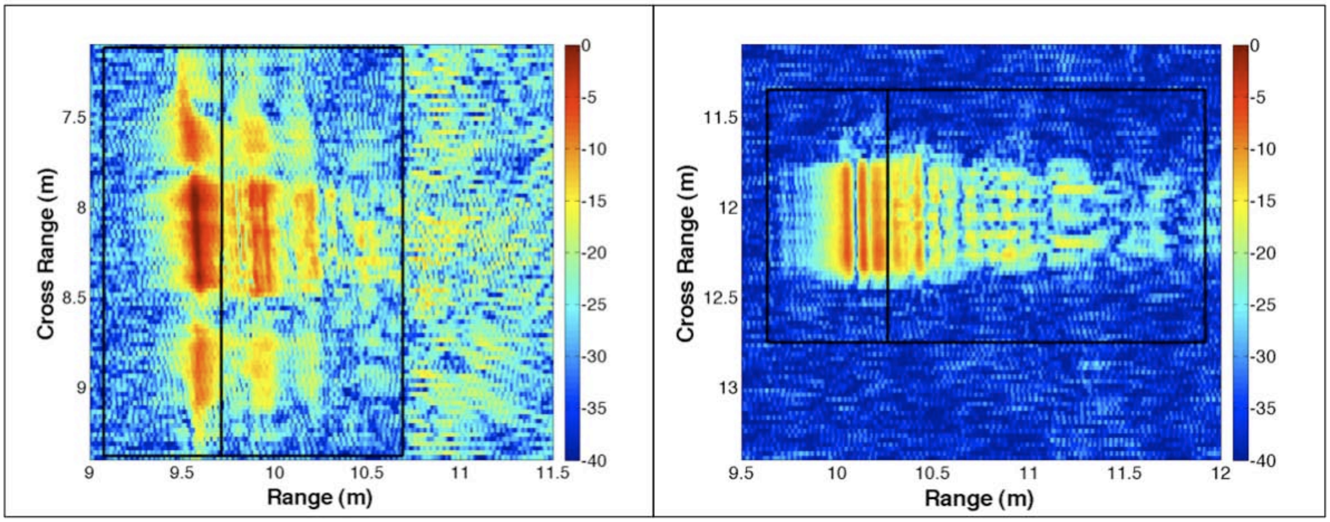
PUBLICATIONS

A. L. España, K. L. Williams, S. G. Kargl, M. Zampolli, T. M. Marston, and P. L. Marston, "Measurements and modeling of the acoustic scattering from an aluminum pipe in the free field and in contact with a sand sediment," Proc. MTS/IEEE OCEANS Conf., 2010 (at press).



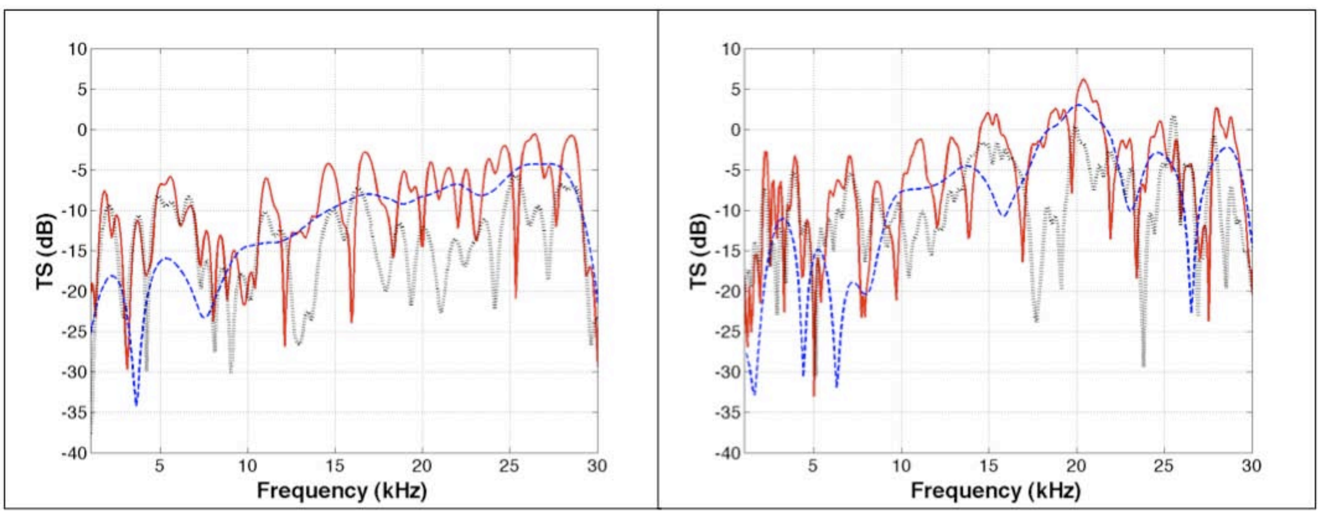
(a) *(b)*

Figure 1. Absolute target strength for the acoustic scattering from an aluminum water-filled pipe as a function of azimuthal angle (a) suspended in the free field and (b) in a proud configuration on a flattened, smooth sediment interface. The pipe is broadside to the source at 0 deg, while end-on corresponds to 90 deg.



(a) *(b)*

Figure 2. SAS image of the aluminum water-filled pipe, oriented broadside to the rail system, mounted (a) in the free field, and (b) proud on a sand sediment. In each of the figures, black boxes are drawn on the image to depict the spatial filter boundaries used to process the data. The smaller, left-most box corresponds to just the specular returns. The box to the right isolates the elastic features. The two boxes together represent the total response of the target. The color scale is in relative dB.



(a) *(b)*

Figure 3. Target strength obtained using the spatial filter boundaries of Fig. 2, for the aluminum water-filled pipe mounted (a) in the free field, and (b) in a proud configuration on the sand sediment. The red (solid) curve represents the total response, the blue (long dashed) curve is just the specular contribution, and the black (short dashed) curve is the elastic response.

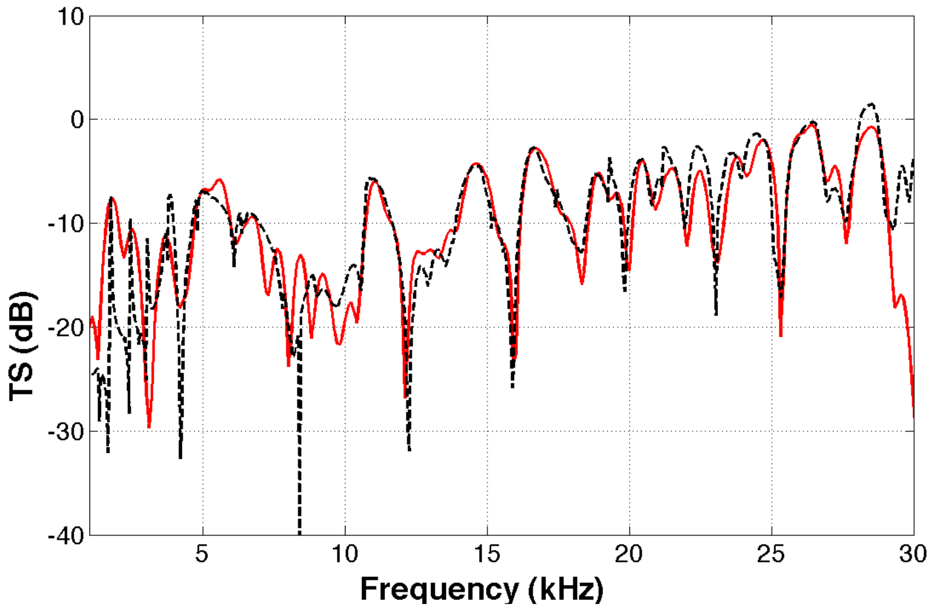


Figure 4. Data-model comparison for aluminum pipe in the free field. Solid red curve is the experimental data taken in the test pond from Fig. 3 (total response). Black dashed curve is the finite element results.

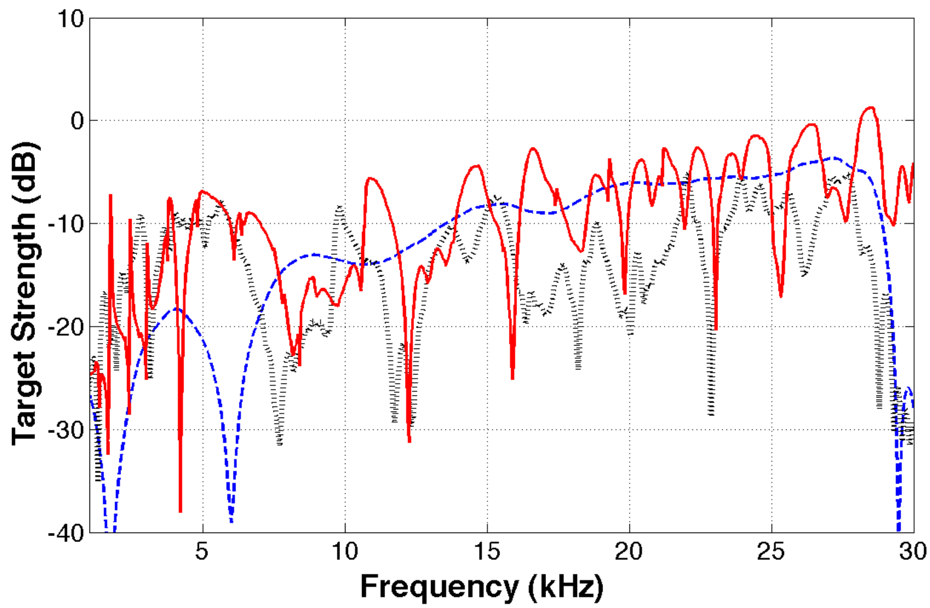


Figure 5. Results of applying a similar spatial filtering technique of Fig. 3 to the FE results of Fig. 4, in order to separate the specular and elastic contributions to the total target response. The red (solid) curve represents the total response (identical to black curve in Fig. 4), the blue (long dashed) curve is the specular contribution, and the black (short dashed) curve is the elastic response.